



Orbiter Entry Aerothermodynamic Flight Testing

STS-119 and STS-125

June 18, 2009

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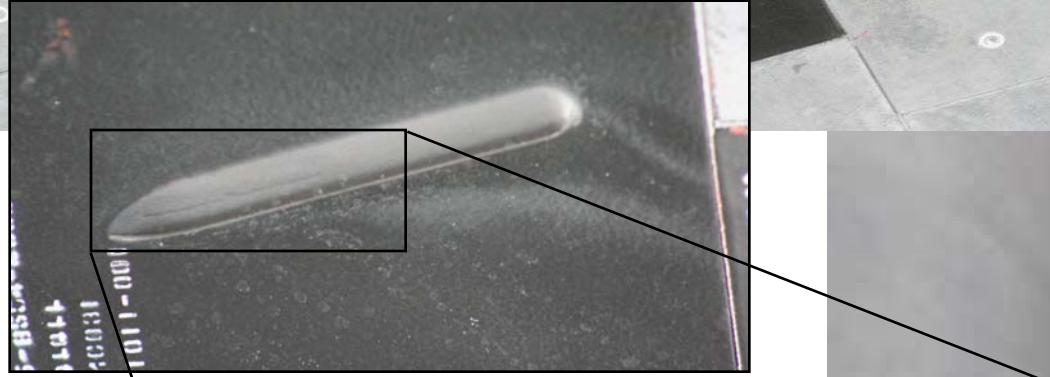
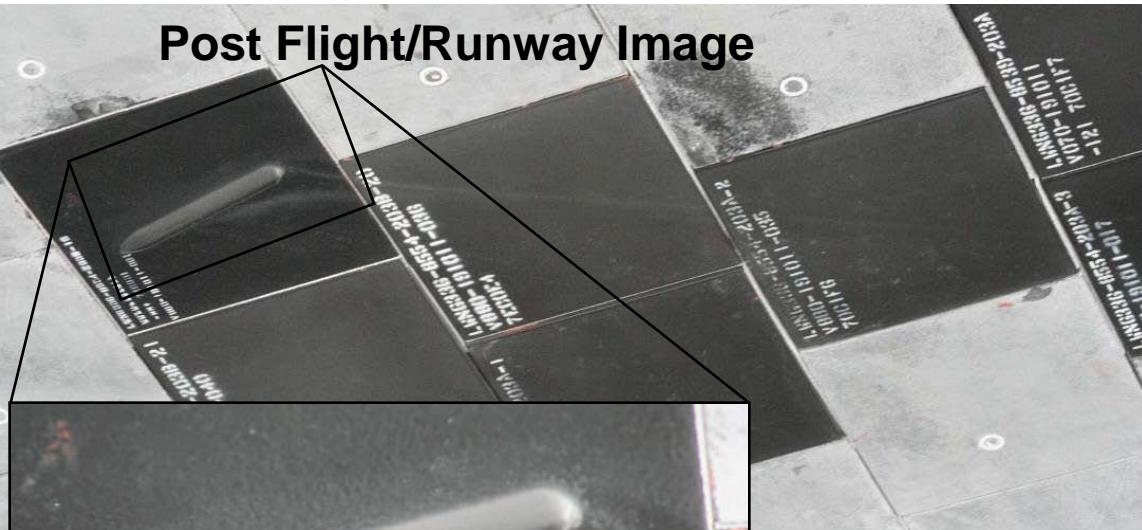
Introduction

- NASA has performed entry flight testing related to boundary layer transition and turbulent heating environments during 2009
- Two projects are involved in implementing the activities and acquiring flight data
 - Orbiter BLT Flight Experiment during STS-119
 - Hypersonic Thermodynamic Infrared Measurements (HYTHIRM) during STS-119 and STS-125
- Orbiter BLT FE has implemented tile surface thermocouples in order to provide in-situ data downstream of a fixed geometry tile protuberance
- HYTHIRM has developed a framework of mission planning and aircraft based telescopic infrared measurements to provide quantitative surface temperature distributions



STS-119 Protuberance Imagery

Post Flight/Runway Image



Protuberance

On-Orbiter RPM Image
Looking Aft



April 21, 2009



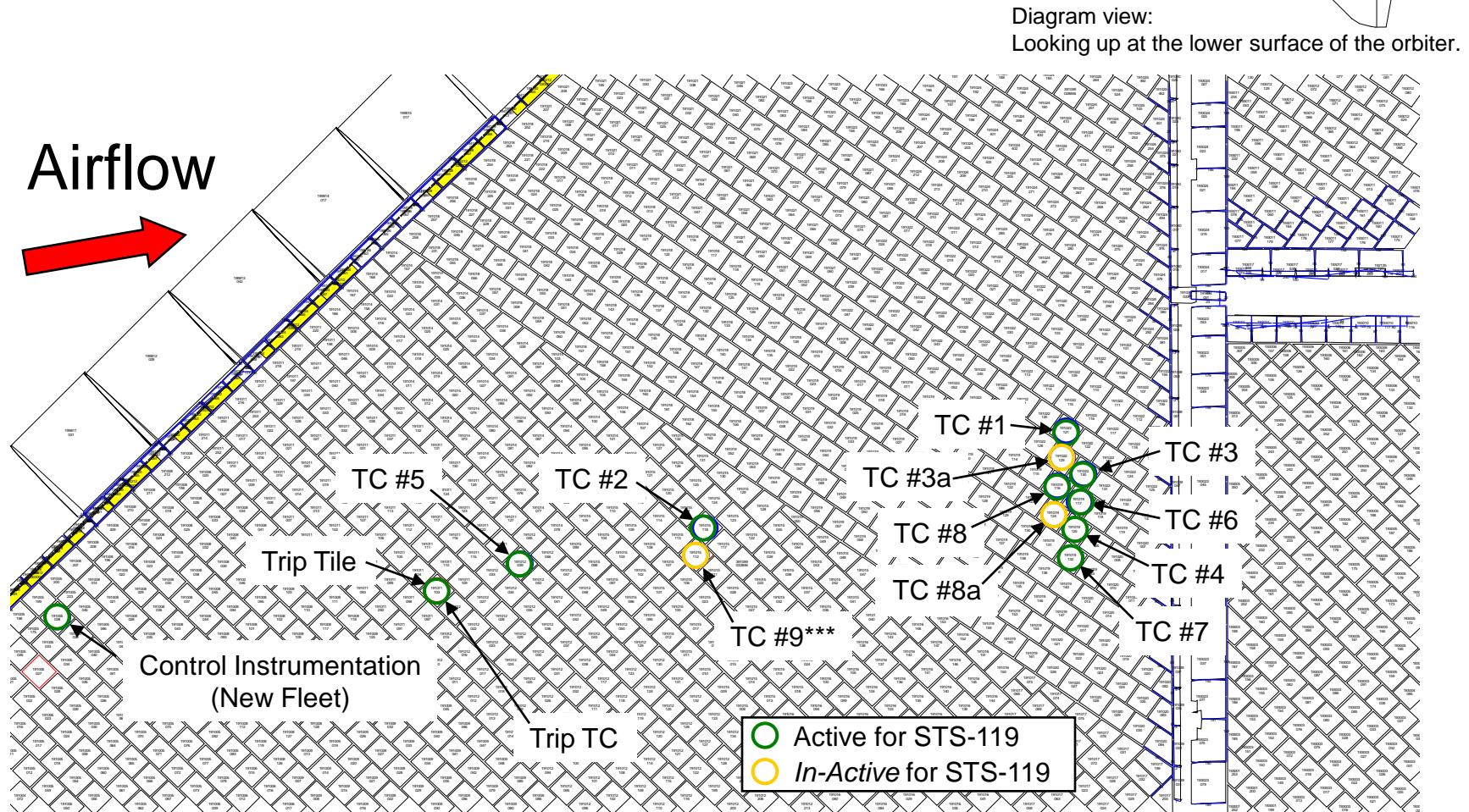
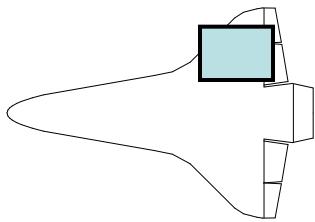
STS-119 BLT FE Summary



- 0.25" Tile Protuberance and Surface TC measurements were implemented on OV-103 prior to STS-119
 - Protuberance height targeted to provide BLT onset near Mach 15
- STS-119 BLT Onset Summary (Based on STS-119 BET trajectory and BLT FE MADS Data)
 - Initial BLT from the 0.25" protuberance at **Mach 15.6** / 969 seconds
 - Initial BLT Onset is very close to RTF V2 BLT tool prediction using BET
 - BLT Tool Predictions: Best Estimate **Mach 15.4** (± 2 -sigma predictions: Mach 18.0->10.8)
 - Effective BLT at Mach 13.1 / 1045 seconds
 - Protuberance BLT at Mach 7.7 / 1224 seconds
 - Fuselage and Port side BLT near Mach 7.9 / 1217 seconds
 - Starboard wing BLT near Mach 10.5 / 1127 seconds
 - This progression of BLT is consistent with expectations
- Surface Temperature Summary
 - Laminar measurements: ~1600 F (consistent with flight history)
 - Turbulent Wedge region: ~1900 F (lower than predictions, but consistent with STS-28)
 - Vortex Heating region: No RCG melt/flow leads to <2500 F conclusion (lower than predictions)
 - BLT Protuberance Peak: ~2000 F (much lower than predictions)

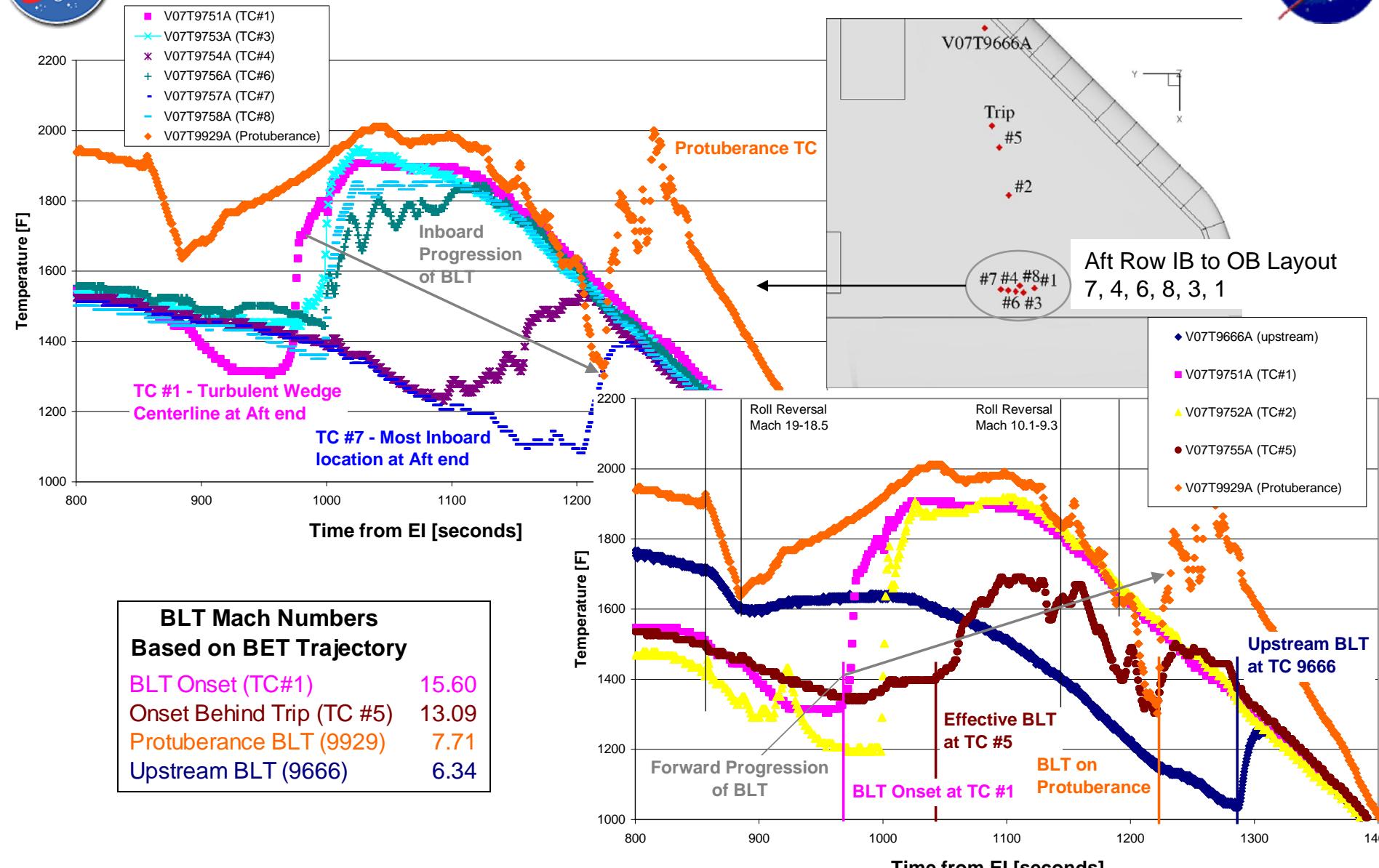


BLT FE Protuberance and TCs





STS-119 BLT FE TC Data





STS-119 BLT FE

Preliminary Observations



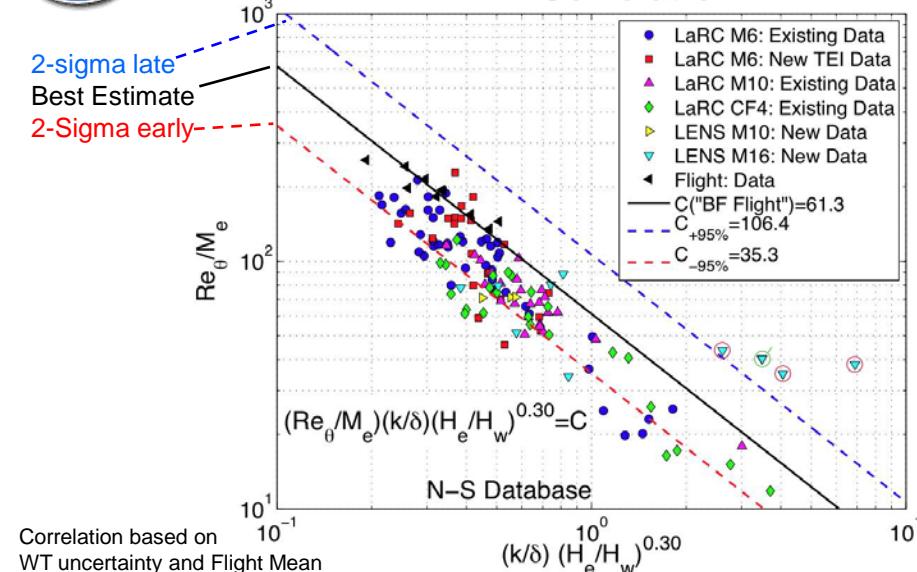
- All BLT FE MADS instrumentation performed nominally
- Initial BLT Onset Downstream of the Protuberance occurred at Mach 15.6
 - This is within the RTF BLT V2 1-sigma prediction (BET prediction: Mach 15.4)
- Protuberance Temperature from MADS data is ~2000 F, compared to 2974 F pre-flight prediction and 2810 F BET prediction
 - Laminar Bump Factor Prediction ~7.5, flight bump factor ~2
- Turbulent wedge half-angle of ~7 degrees based on BLT FE TCs
- Starboard ABLT occurred at Mach 10.5 (opposite side of BLT FE)
 - Corroborated by GN&C post-flight assessments, HyThirm IR data and MADS TCs
 - OML geometry that led to STS-119 ABLT is unknown, but region has been isolated to near the STBD side of the nose gear door based on turbulent wedge tool assessments
 - Historical BLT onset is below Mach ~11 due to typical vehicle roughness
 - Does Not include flights with early BLT due to protruding gap fillers or tile damage
- TPS reviewed visually and via OML scan data – No discernible OML change
- **All objectives for first flight of the BLT Flight Experiment accomplished**
- STS-128 / 0.35" protuberance RTF BLT V2 onset prediction of Mach ~18



Orbiter Return To Flight BLT Correlation



RTF BLT V2 Correlation



Accuracy of various BLT Engineering Correlations with Orbiter RTF Data

Proposed Correlation	Correlation Equation	Ground-Based			Ground-Based + Flight		
		R	$\Delta C/C$	σ_C/\bar{C}	R	$\Delta C/C$	σ_C/\bar{C}
1	$Re_\theta/M_e \times k/\delta = C$	-0.87	1.26	19.9%	-0.88	1.25	21.2%
2	$Re_\theta/M_e \times k/\delta^* = C$	-0.90	1.08	7.3%	-0.87	1.32	34.9%
3	$Re_\theta/M_e \times (k/\delta)(T_e/T_w)^{0.16} = C$	-0.89	1.14	14.5%	-0.89	1.20	23.6%
$\Rightarrow 4$	$Re_\theta/M_e \times (k/\delta)(H_e/H_w)^{0.30} = C$	-0.91	1.04	8.9%	-0.91	1.10	19.9%
5	$\rho_k u_k k / \mu_w = C$	-0.79	2.51	30.9%	—	—	—
$\Rightarrow 6$	$Re_k^{0.6} \times [Re_\theta \cdot (\mu_e/\mu_k)]^{0.4} = C *$	-0.87	1.09	14.8%	-0.84	1.30	35.0%

* Results are for $n = -0.6$ for all data

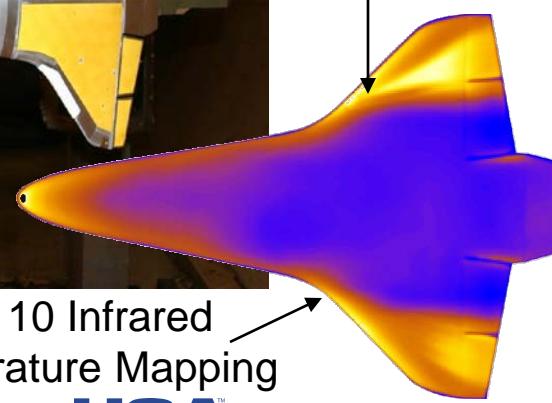
Ref: King, R.A., Kegerise, M.A. and Berry, S.A., "Proposed Protuberance Correlations for the Next Generation BLT Tool (vsn 2)", EG-SS-07-07, March 30, 2007

CUBRC MH-13
Wind Tunnel Model



Cassady, et al
NASA/TP-2007-214758

Turbulent Wedge from BLT Trip



LaRC Mach 10 Infrared Surface Temperature Mapping



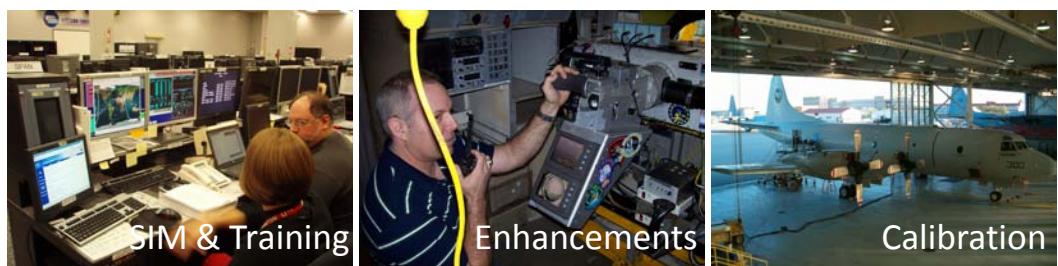


HYTHIRM STS-119

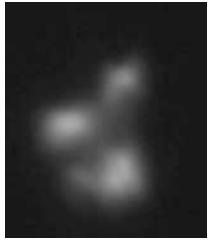
Hypersonic Thermodynamic Infrared Measurements



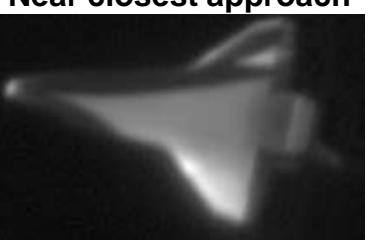
STS-119 success criteria: To obtain spatially resolved infrared imagery during a flight experiment that will provide a quantified surface temperature map of the Shuttle during hypersonic re-entry



Long range



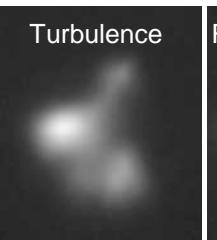
Near closest approach



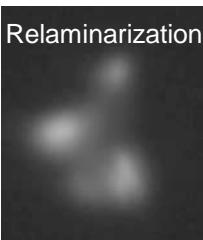
Receding...



Turbulence



Relaminarization



Turbulence



Development of asymmetric boundary layer transition

Turbulent flow from wing BLT protuberance

Turbulent flow from unknown origin

Radiometric-Calibrated
Temperature Image
Frame averaging applied

STS-119
Mach ~ 8.5
Mar 28, 2009



HYTHIRM STS-125

Hypersonic Thermodynamic Infrared Measurements



STS-125 success criteria: To obtain spatially resolved infrared imagery that will provide a quantified surface temperature map of the Shuttle during a high Mach hypersonic re-entry



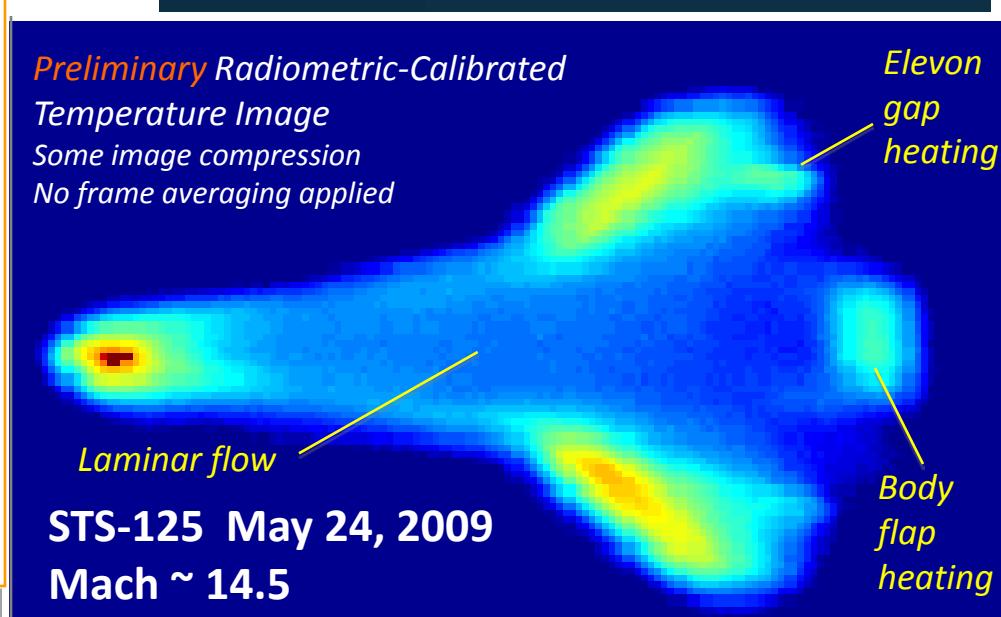
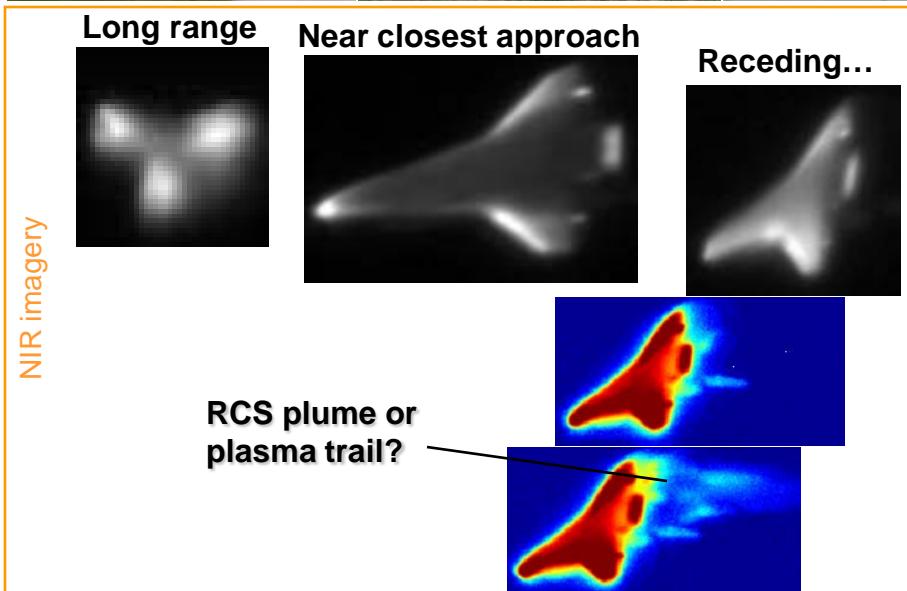
Dress Rehearsal & Calibration at KSC



FL MARS deployment



Mission success





Back-up

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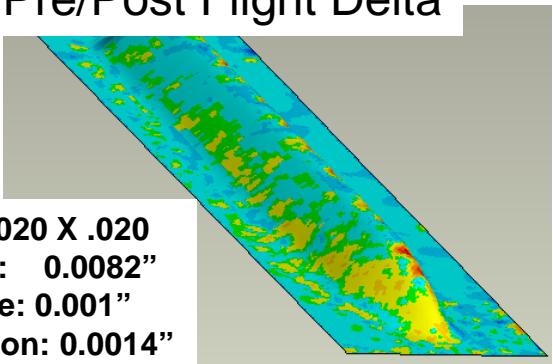
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STS-119 OML Scans



Optigo Pre/Post Flight Delta



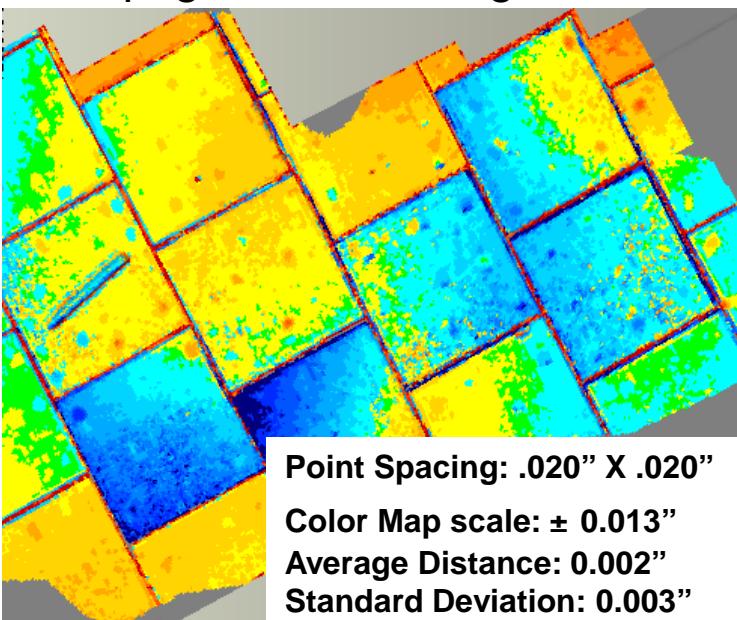
Point Spacing: .020 X .020

Color Map scale: 0.0082"

Average distance: 0.001"

Standard deviation: 0.0014"

Optigo Pre/Post Flight Delta



Point Spacing: .020" X .020"

Color Map scale: ± 0.013"

Average Distance: 0.002"

Standard Deviation: 0.003"

- Pre-flight OML Scans performed
 - Metris Laser/Radar, Optigo and Z-scanner
- Post flight OML Scans Performed to establish geometry change during flight
 - Metris Laser/Radar and Optigo
- Delta Geometry Assessment Accuracy
 - 0.001" -> 0.005" Depending on Resolution
- No Discernible Geometry change

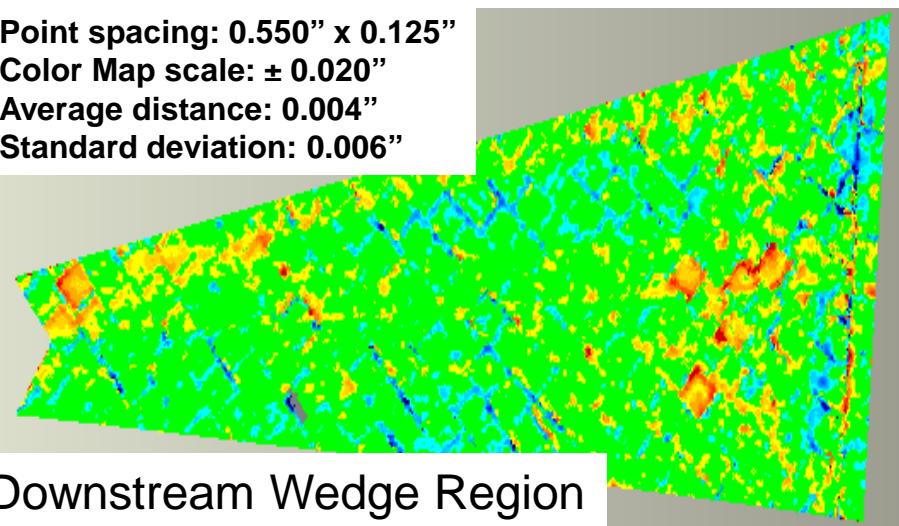
Metris Laser/Radar Pre/Post Flight Delta

Point spacing: 0.550" x 0.125"

Color Map scale: ± 0.020"

Average distance: 0.004"

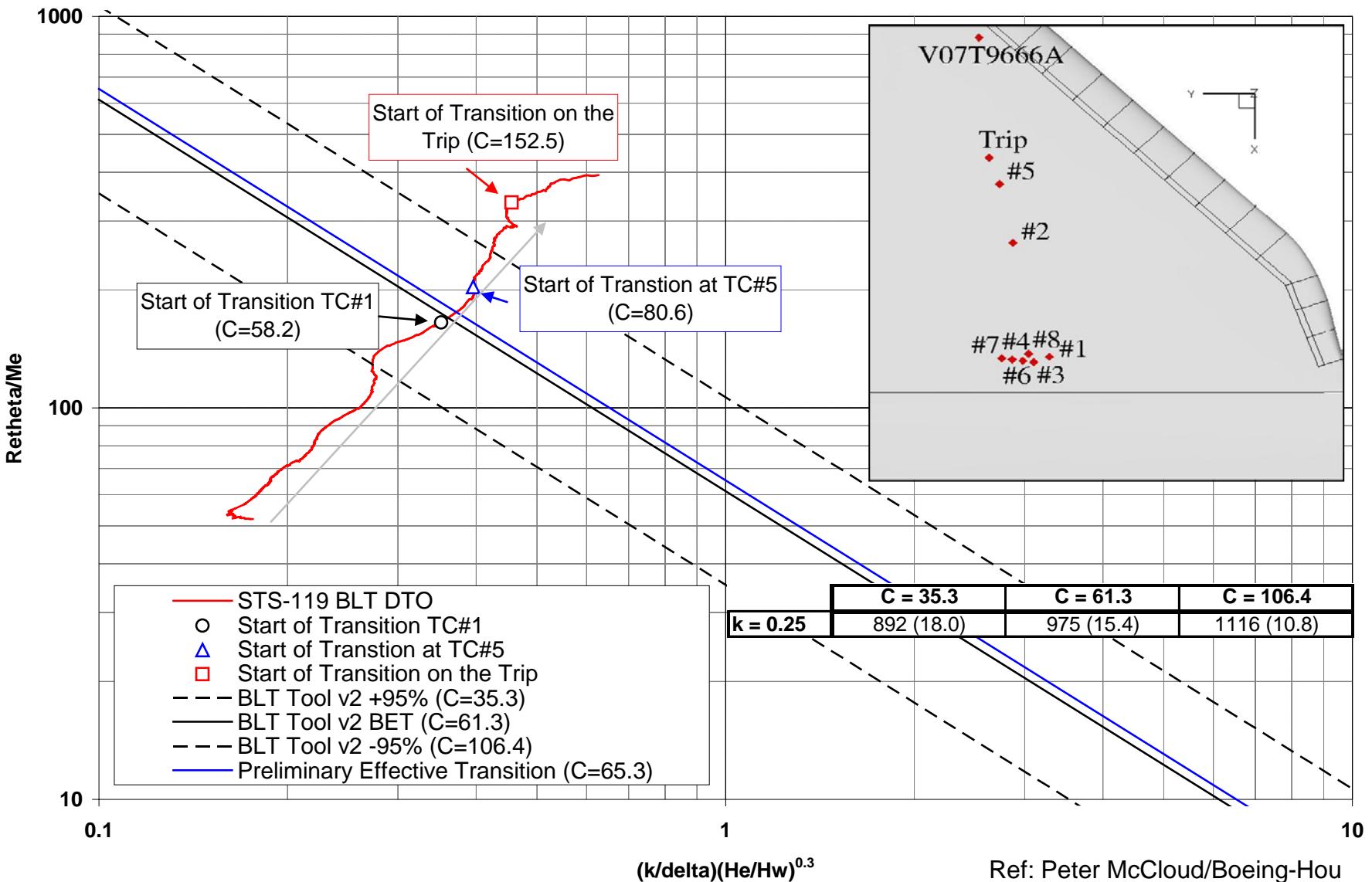
Standard deviation: 0.006"



Downstream Wedge Region

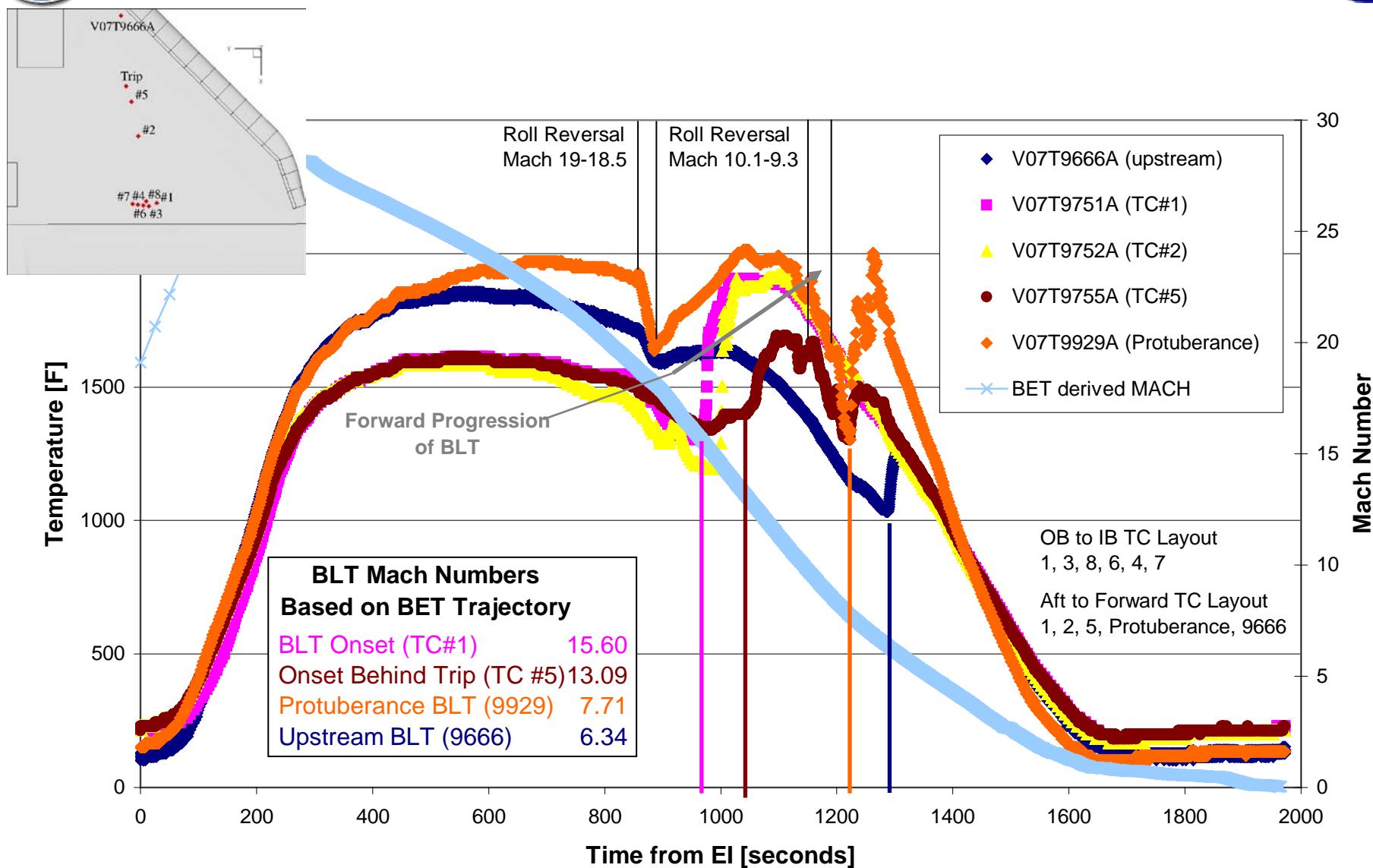


STS-119 RTF BLT V2 Correlation



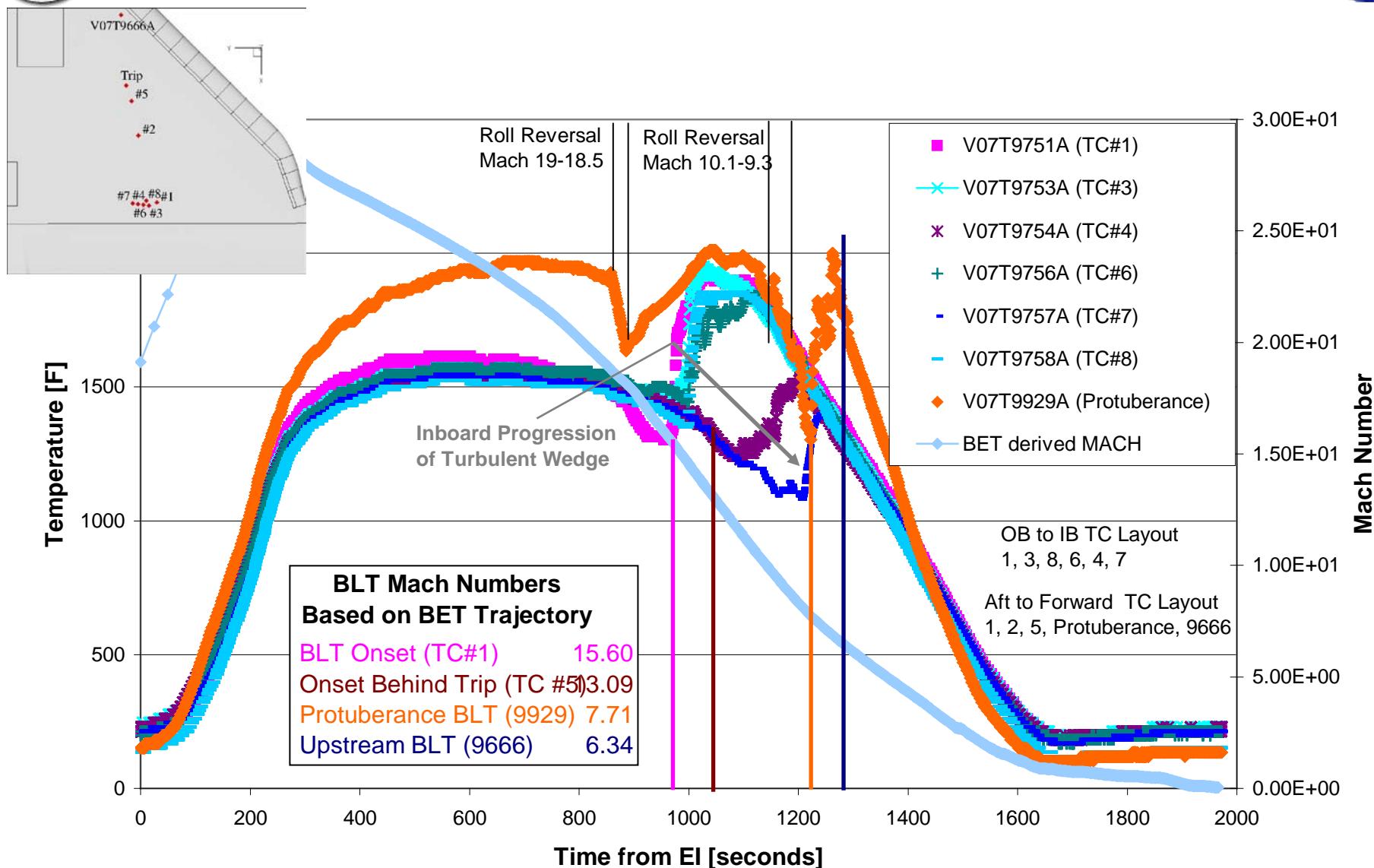


STS-119 BLT FE TC Data



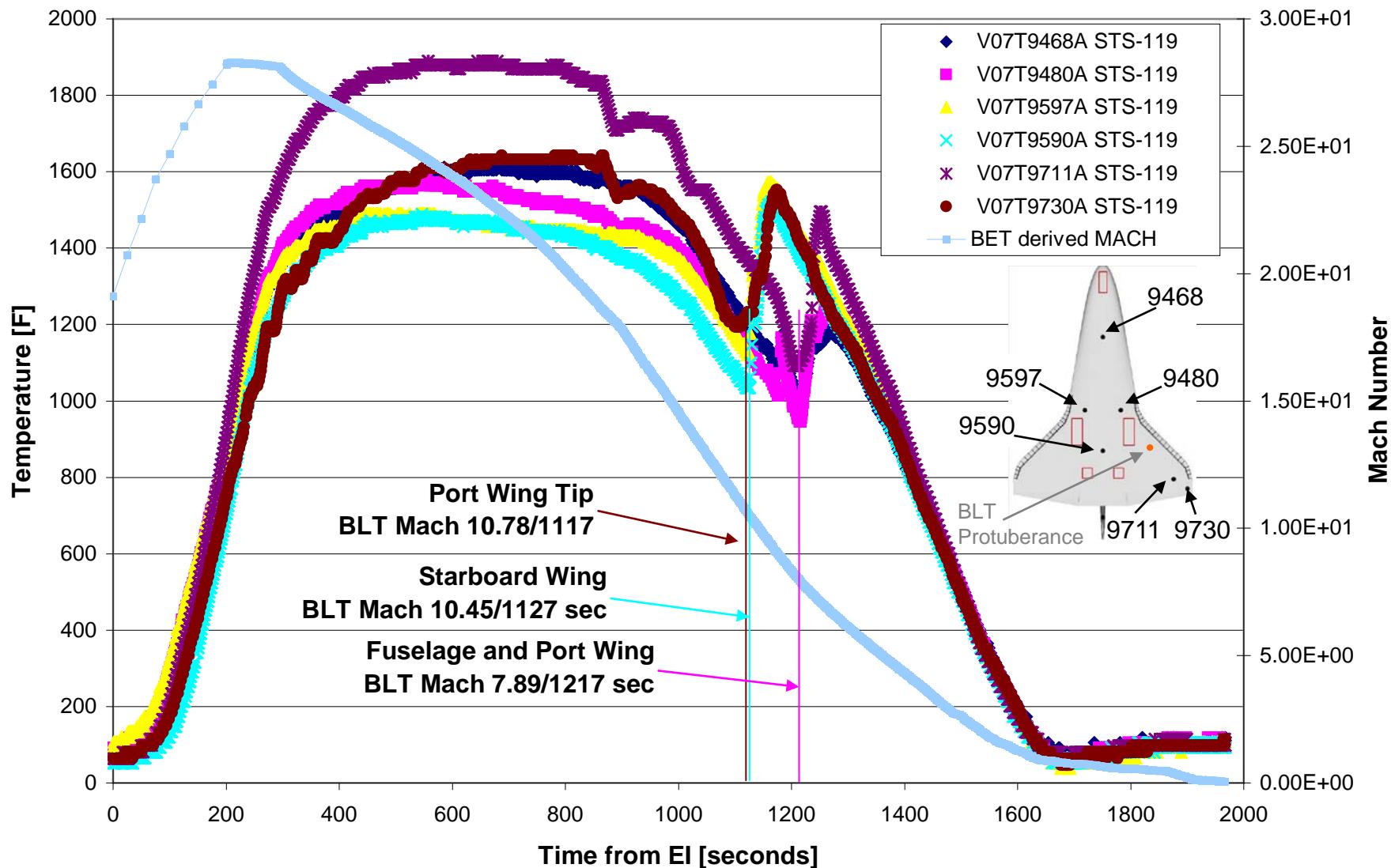


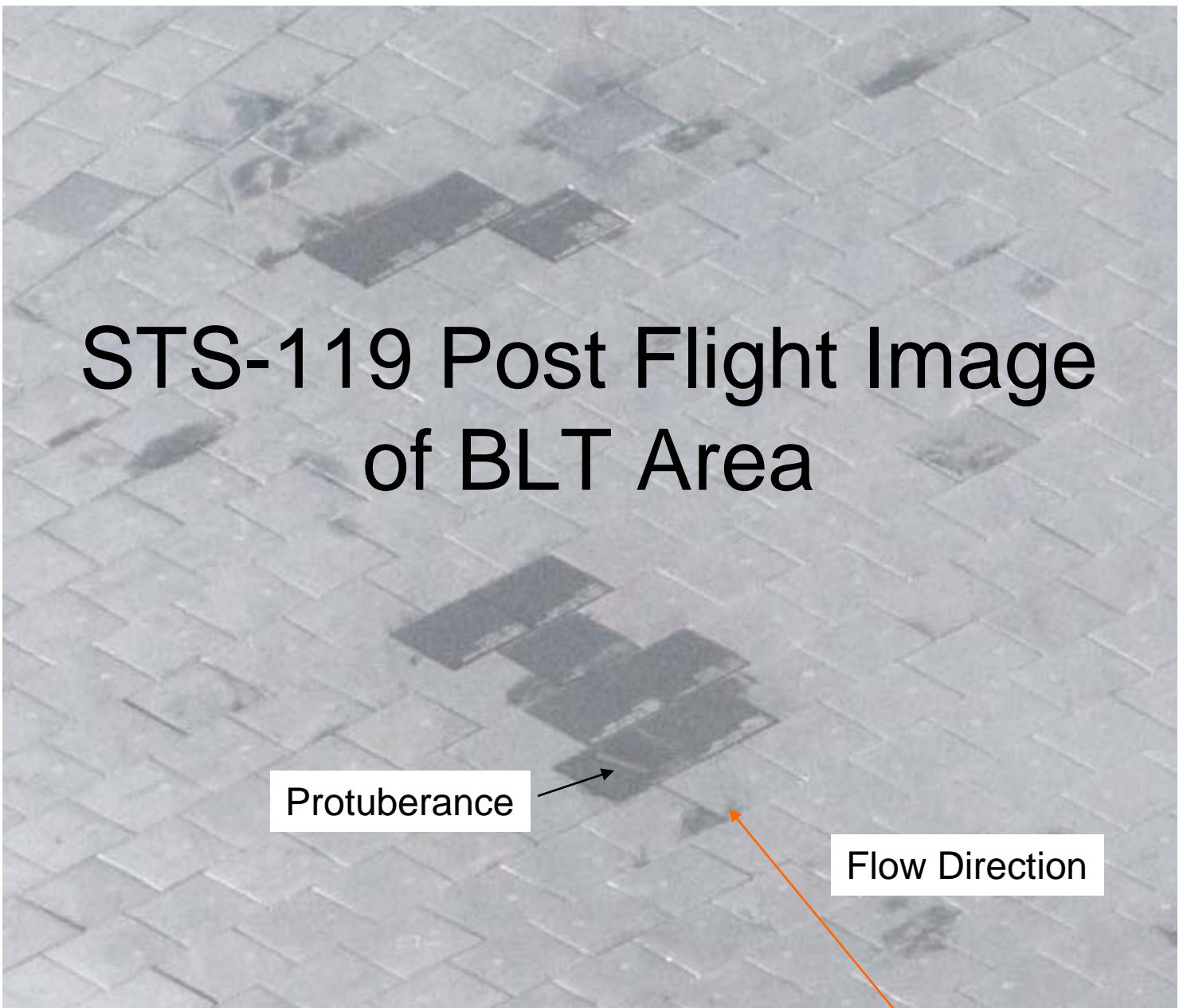
STS-119 BLT FE TC Data





STS-119 Windward MADS TCs







STS-119 Post Flight Image of Aft BLT Area



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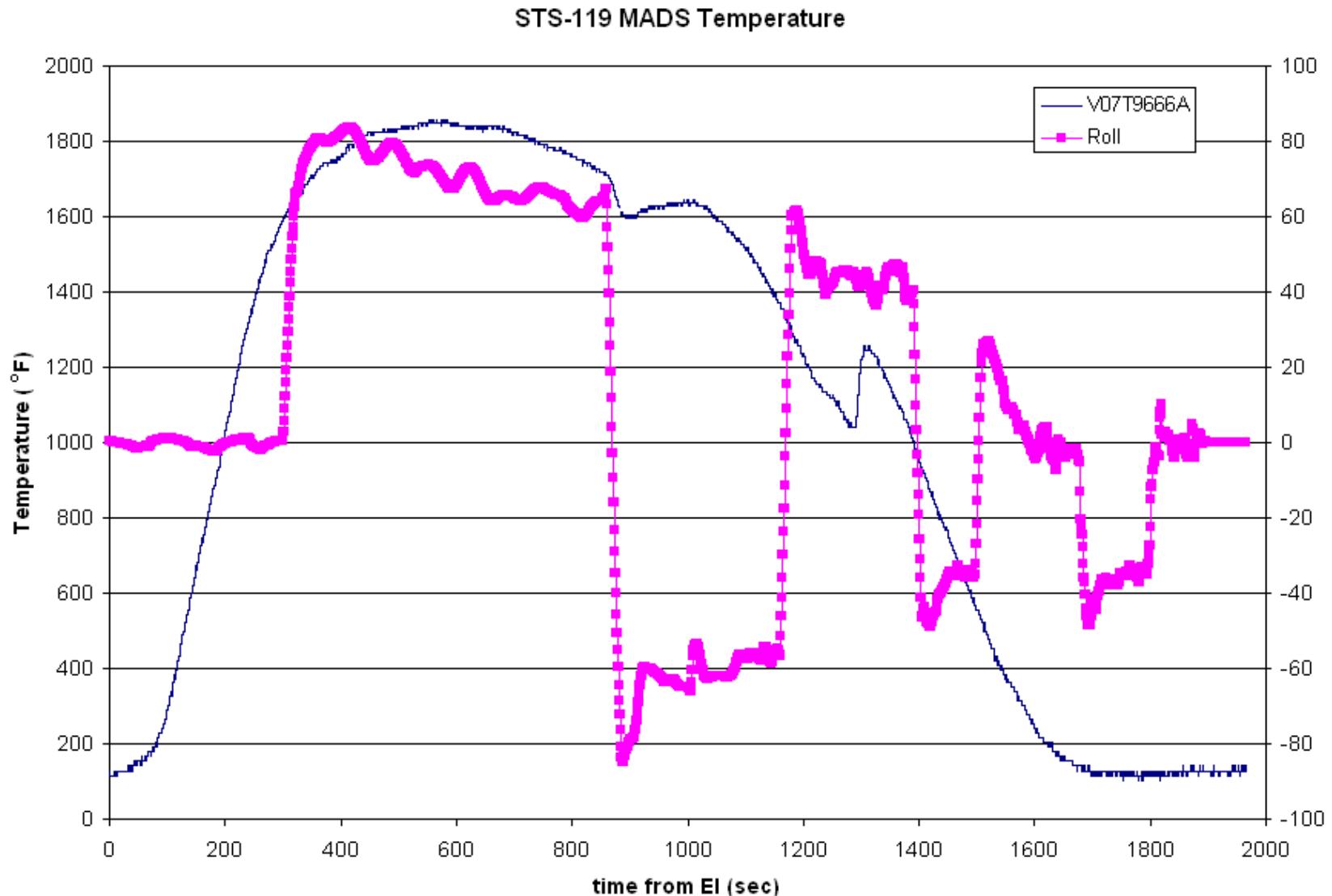


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STS-119 Roll versus Time from EI



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USA
United Space Alliance

BOEING

Time from EI Estimated from EOM Trajectory and MADS Nav Data
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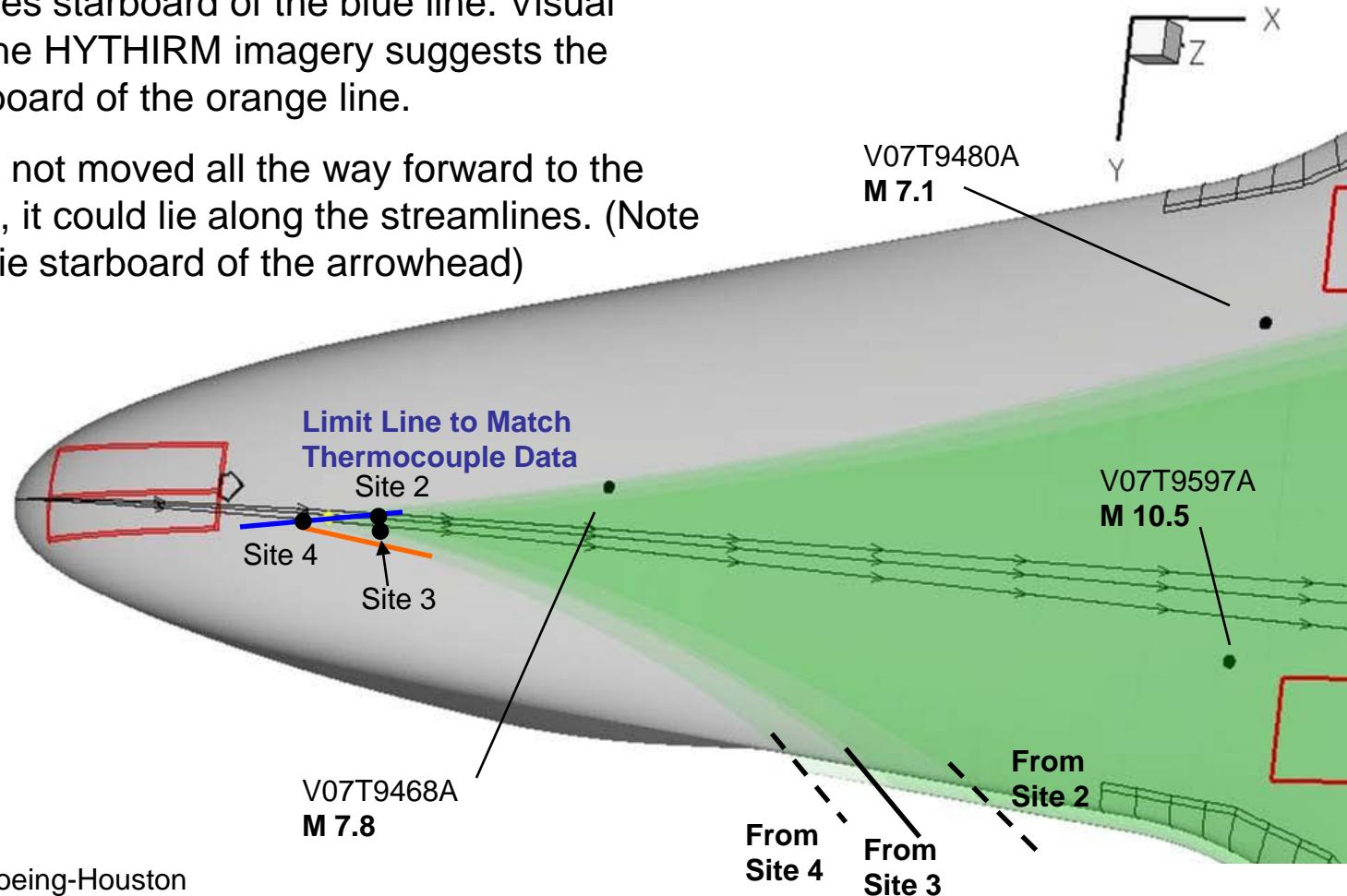


STS-119 Starboard ABLT Wedge Assessment



If the wedge starts at the source, MADS data suggests that the source lies starboard of the blue line. Visual Comparison of the HYTHIRM imagery suggests the damages lies inboard of the orange line.

If the wedge has not moved all the way forward to the transition source, it could lie along the streamlines. (Note the streamlines lie starboard of the arrowhead)



Peter McCloud / Boeing-Houston



STS-128 BLT FE Instrumentation Recommendation

